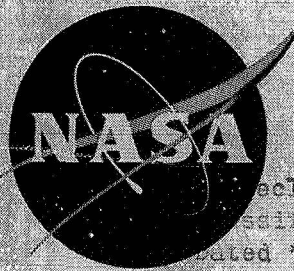


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TECHNICAL MEMORANDUM

X-460

FLUTTER INVESTIGATION OF MODELS HAVING THE PLANFORM
OF THE NORTH AMERICAN X-15 AIRPLANE WING OVER A
RANGE OF MACH NUMBERS FROM 0.56 TO 7.3

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SUMMARY

Results of an experimental and theoretical investigation of the flutter characteristics of low-aspect-ratio wing panels having the planform of the North American X-15 airplane are presented. The models had two different airfoil sections and were tested in a range of Mach numbers from 0.56 to 7.3.



For the configurations tested, the experimental results indicate that changing the airfoil from a flat plate (zero thickness) to a modified 66A005 airfoil section derived by the manufacturer had a small effect on the flutter speed at Mach numbers from 0.56 to 3.0 and a large destabilizing effect at a Mach number of 7.3.

The data calculated for the subsonic and transonic Mach numbers with the use of a three-dimensional kernel-function approach are conservative but indicate the same trend as the experimental data.

The calculations for the supersonic and hypersonic Mach numbers utilized air forces derived from two-dimensional piston theory. The results are generally unconservative and indicate a small effect of increased thickness at supersonic Mach numbers and a large destabilizing effect at a Mach number of 7.3.

INTRODUCTION

As the performance capabilities of aircraft become higher, the use of thin, low-aspect-ratio airfoils is indicated. Therefore, enhancing the fund of information on the flutter characteristics of



such airfoils becomes increasingly important. In the present investigation, semispan models which had an unswept 70-percent-chord line, a panel aspect ratio of 1.08, and a panel taper ratio of 0.273 (North American X-15 wing panel planform) were tested for flutter in a range of Mach numbers from 0.56 to 7.3. The effect of changing the airfoil from a thin flat plate to a modified 66A005 airfoil section (designated by the manufacturer) was investigated.

The tests were performed in the 2-foot transonic aeroelasticity tunnel, the 9- by 18-inch supersonic aeroelasticity tunnel, the Mach 5 blowdown jet, and the hypersonic aeroelasticity tunnel, all at Langley Research Center.

Calculations of the flutter speed of representative models were made. For subsonic and transonic speeds, a three-dimensional flutter analysis with the use of the kernel-function approach was made by following the method described in reference 1. For supersonic and hypersonic speeds, the two-dimensional analysis with the use of the aerodynamic forces derived from piston theory was made by following the method described in reference 2.

SYMBOLS

a	speed of sound, ft/sec
b	half chord of wing at $3/4$ semispan, ft
c	local chord of wing, ft
f	natural frequency of wing, cps
l	length of wing panel, ft
M	Mach number
m	mass of exposed wing, slugs
q	dynamic pressure, lb/sq ft
t	thickness of wing, percent c
x	streamwise coordinate, ft
y	spanwise coordinate, ft
z	vertical coordinate, ft

$$\mu \quad \text{mass ratio} \quad \frac{m}{\pi \rho \int_0^l \left(\frac{c}{2}\right)^2 dy}$$

ρ density of test medium, slugs/cu ft

ω circular frequency, radians/sec

Subscripts:

1,2,3 indicate natural frequencies in order of increasing frequency

f indicates the flutter condition

u indicates upper surface

l indicates lower surface

ex experimental

th theoretical

APPARATUS AND TESTS

Models

Geometrical characteristics.— The models had a panel aspect ratio of 1.08, a panel taper ratio of 0.273, and an unswept 70-percent-chord line. (This is the same planform as the North American X-15 airplane wing.) There were two airfoil-section configurations. One section configuration was rectangular with sharp leading and trailing edges, the thickness values ranging from 0.295 to 0.58 percent chord. The other configuration used the rectangular metal section as a core and a low-density, flexible plastic foam covering to give the modified 66A005 airfoil section derived by the manufacturer and shown in figure 1. Throughout the paper the models having the modified 66A005 airfoil are designated by a suffix A in the model designation. Both airfoil configurations had a constant thickness in percent chord along the span. All models had the elastic axis and center of gravity located approximately along the 50-percent-chord line. Details of the models are given in table I.

Vibration characteristics.— The dynamic characteristics of each model were determined in the laboratory by using the test setup shown in figure 2. The model was clamped rigidly to a backstop. An air shaker

similar to the one described in reference 3 was placed under the wing and the forcing frequency was varied until resonance in one of the natural-vibration modes occurred. The mode shapes of each model were obtained by measuring the amplitude of the white lines on a photograph of the vibrating model such as is shown in figure 2. This photographic technique is described in reference 4. Sketches of the mode shapes of the first three natural frequencies of a representative model (S-1) are shown in figure 3. The first two natural frequencies of all the models tested are presented in table II.

Tunnels and Test Procedure

Mach numbers of 0.56 to 1.19.- Models T-1 and T-1A were flush mounted as shown in figure 4(a) in the Langley 2-foot transonic aeroelasticity tunnel which is a conventional slotted-throat, single-return type tunnel equipped to use either air or Freon 12 as a test medium. The fluid density and Mach number may be varied independently. The fluid density was set at various levels by presetting the stagnation pressure. The Mach number was then varied by changing the tunnel fan rotational speed. For each flutter condition encountered, the various tunnel pressures and temperature were recorded. Eleven flutter points were obtained with model T-1 and ten flutter points were obtained with model T-1A.

Mach numbers of 1.3, 1.64, 2.0, and 3.0.- Models S-1, S-1A, S-2, and S-2A were flush mounted as shown in figure 4(a) in the Langley 9- by 18-inch supersonic aeroelasticity tunnel which is an intermittent blow-down type tunnel operating from high pressure to a vacuum. For each model the tunnel was started and the stagnation pressure increased until flutter occurred.

Mach number of 5.0.- Model S-3 was tested in the Langley Mach 5 blowdown jet which utilizes preheated pressurized air and exhausts to the atmosphere. The model was flush mounted as shown in figure 4(a).

Mach number of 7.3.- All of the H-series models were tested in the 8-inch-diameter nozzle of the Langley hypersonic aeroelasticity tunnel which operates from high to low pressure and uses helium as a medium. The dynamic pressure can be varied from 100 to 5,000 lb/sq ft. The models were installed in the test section in the mount shown in figure 4(b).

Instrumentation

A recording oscillograph was used in the tests to obtain continuous records of the output of strain gages which were oriented on the models to indicate primarily bending and torsion strains. For the subsonic and

transonic tests the various indicated pressures and temperatures could be recorded directly from tunnel instruments. In the supersonic and hypersonic tests, simultaneously recorded with the outputs of the strain gages were the outputs from a tunnel thermocouple and pressure cell from which tunnel stagnation temperature and pressure could be determined.

ANALYSIS

For the subsonic and transonic speeds the calculated flutter data were obtained by using the three-dimensional kernel-function approach for airfoils of zero thickness as applied in reference 1. The first three experimentally determined natural vibration modes were used.

The calculated data for the supersonic and hypersonic Mach numbers were calculated by following the method of reference 2, with the use of the aerodynamic forces derived from two-dimensional piston theory. The first three experimentally determined natural vibration mode shapes were used.

RESULTS AND DISCUSSION

The results of the investigation are summarized in table II. Table II(a) includes the data from $M = 0.56$ to $M = 1.19$ and table II(b) presents the data from $M = 1.3$ to $M = 7.3$. With the model designation and Mach number are given the first natural frequencies, the experimental and theoretical flutter frequencies for the supersonic and hypersonic Mach numbers, the thickness of the model in percent chord, mass of exposed wings, the density of the test medium, the sound speed at flutter, the dynamic pressure at flutter, the mass ratio μ , and the stiffness-altitude parameter $\frac{b\omega_2^2}{a} \sqrt{\mu}$. The b used in the stiffness-altitude parameter is that at $\frac{3}{4} l$. In figure 5, the experimental data at low Mach numbers ($M \approx 0.56$ to 1.19) have been plotted for model T-1 which had a flat-plate airfoil section and the same model covered with plastic foam to give the modified 66A005 airfoil section as described in figure 1 (model T-1A). The data show a moderately stabilizing effect of increasing the thickness at subsonic Mach numbers and little or no thickness effect at $M = 1.0$.

A comparison of the experimental data for the thin, flat-plate models and the modified 66A005 airfoil section models from $M = 1.3$ to $M = 7.3$ is presented in figure 6. Very little consistent effect of changing the airfoil section from a flat plate to a modified 66A005 airfoil is evident up to a Mach number of 3.0; however, a large destabilizing effect of the

change is indicated at $M \approx 7.3$. It may be noted that the data points for models H-2 and H-2A were obtained in two tunnel runs for each configuration under what were apparently similar conditions. The reasons for the large spread in the experimental data at $M \approx 7.3$ are not known although effects of transient heating of the model, clamping of the model, and very rapid changes in tunnel conditions at the time of flutter could be factors. A few separate tests were made with slowly varying tunnel conditions to minimize transient heating and with a model-support system designed to minimize damping variations; however, the tests did not isolate the causes of the variations in flutter coefficient at $M = 7.3$. Figure 7 presents the ratio of experimental to theoretical flutter frequency for the two different airfoil configurations in the supersonic and hypersonic Mach number range. A summary of the experimental and theoretical data is presented in figure 8 in the form of a stiffness-

altitude parameter $\frac{b\omega_2}{a} \sqrt{\mu}$ plotted against Mach number. The theoretical data at subsonic and transonic speeds indicate the same trend as the experimental data and seem to be approaching good agreement as the speed approaches $M = 1.0$. The theoretical data at the supersonic and hypersonic Mach numbers are unconservative but appear to indicate the same general trends as the experimental data. The theoretical data indicate a destabilizing effect of thickness above $M = 3.5$. This is in agreement with the calculated piston-theory results reported in reference 5 for wings having similar properties to those of the present models.

CONCLUDING REMARKS

Experimental and theoretical results of a flutter investigation of low-aspect-ratio wing panels (X-15 wing planform) having two different airfoil sections (zero and 0.05 thickness) are compared in a range of Mach numbers from 0.56 to 7.3. For the configurations tested, the experimental results indicate a small effect of increased airfoil thickness on the flutter speed from a Mach number of 0.56 to 3.0 and a large destabilizing effect at a Mach number of 7.3.

The calculated results for the subsonic and transonic Mach numbers with the use of the three-dimensional kernel-function approach, indicate the same trend as the experimental data; however, these results indicate a lower dynamic pressure for flutter (a conservative effect).

The results calculated for the supersonic and hypersonic Mach numbers using air forces derived from two-dimensional piston theory indicate generally a higher (unconservative) dynamic pressure for flutter than the experimental data. The theory shows a small effect of increase of thickness for the lower supersonic Mach numbers; however, there is a

large adverse effect of thickness at Mach number 7.3, a trend also shown by the experimental data.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., December 16, 1960.

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1. Woolston, Donald S., and Sewall, John L.: Use of the Kernel Function in a Three-Dimensional Flutter Analysis With Application to a Flutter-Tested Delta-Wing Model. NACA TN 4395, 1958.
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3. Herr, Robert W.: A Wide-Frequency-Range Air-Jet Shaker. NACA TN 4060, 1957.
4. Herr, Robert W.: Preliminary Experimental Investigation of Flutter Characteristics of M and W Wings. NACA RM L51E31, 1951.
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TABLE I.- MODEL DETAILS

Model designation	Mach number of test	Model panel length, l , in.	$t/c \times 100$	Material	Airfoil section
T-1 T-1A	0.56 to 1.2	6.0	0.30 5.00	Steel Steel and foam	Rectangular 66A005 modified
S-1 S-1A	1.3, 1.64, and 2.0	6.0	.50 5.00	Steel Steel and foam	Rectangular 66A005 modified
S-2 S-2A	3.0	6.0	.32 5.00	Steel Steel and foam	Rectangular 66A005 modified
S-3	5.0	6.0	.53	Steel	Rectangular
H-1 H-2 H-3 H-4 H-5 H-6 H-7 H-8 H-9	7.3	4.0	.395 .327 .295 .310 .430 .580 .360 .438 .500	Steel Steel Aluminum	Rectangular
H-2A			5.000	Steel and foam	66A005 modified

TABLE II.- SUMMARY OF EXPERIMENTAL DATA

(a) Subsonic and transonic Mach numbers

Model designation	Mach number	f ₁ , cps	f ₂ , cps	f ₃ , cps	t, percent of c	M, slugs	ρ, slugs/cu ft	a, ft/sec	q _f , lb/sq ft	μ	$\frac{bu_2}{a} \sqrt{\mu}$
T-1	0.56	33	85	121	0.3	0.0060	0.0063	497	245	10.3	0.575
	.62						.0049	499	239	13.2	.640
	.74						.0034	497	235	19.0	.771
	.80						.0027	499	219	23.9	.862
	.86						.0020	501	193	32.3	.999
	.93						.0015	503	161	43.0	1.153
	.96	1.07 1.10					.0012	507	142	53.8	1.274
	.97						.0011	508	129	58.6	1.326
	.99						.00089	510	114	72.4	1.472
	1.07						.00069	511	104	93.4	1.664
	1.10						.00055	519	90	117.0	1.836
T-1A	0.56	27	68	105	5.0	0.0080	0.0063	518	268	13.7	0.503
	.60						.0061	516	307	14.1	.512
	.67						.0047	519	296	18.3	.581
	.81						.0034	518	301	25.3	.684
	.84						.0033	517	319	26.0	.695
	.94						.0016	524	194	53.7	.986
	.95	1.03 1.19					.00156	522	197	55.1	1.003
	.98						.0008	524	111	107.5	1.394
	1.03						.00053	525	78	162.0	1.710
	1.19						.00047	522	91	182.8	1.824

TABLE II.- SUMMARY OF EXPERIMENTAL DATA - Concluded

(b) Supersonic and hypersonic Mach numbers

Model designation	Mach number	f_1 , cps	$f_{f,th}$, cps	f_2 , cps	$f_{f,ex}$, cps	t , percent of c	M, slugs	ρ , slugs/cu ft	a , ft/sec	q_f , lb/sq ft	μ	$\frac{b\sqrt{2}}{a} \sqrt{\mu}$
S-1	1.3	61	203	170	112	0.5	0.0099	0.00171	982	1,395	62.9	1.422
S-1A	1.3	53	194	158	100	5.0	.0125	.00185	984	1,510	73.4	1.425
S-1	1.64	61	203	170	128	.5	.0099	.00182	916	2,058	59.1	1.479
S-1A	1.64	53	192	158	114	5.0	.0125	.0016	920	1,820	84.9	1.640
S-1	2.0	61	203	170	141	.5	.0099	.00176	846	2,515	51.1	1.628
S-1A	2.0	53	178	158	120	5.0	.0125	.00158	874	2,417	86.0	1.738
S-2	3.0	39	131	132	103	.32	.007	.00085	699	1,866	89.5	1.850
S-2A	3.0	35	143	114	85	5.0	.0091	.00089	714	1,570	111.1	1.745
S-3	5.0	65	131	180	151	.53	.011	.00268	586	11,570	44.6	2.126
H-1	7.3	64	131	133	112	.395	.00258	.000107	793	1,750	883.0	3.443
H-2		51	116	164	85	.327	.00202	.0001228	798	2,090	600.0	3.478
H-2		51		164	85	.327	.00202	.00019	798	3,170	389.4	2.796
H-3		43		143	66	.295	.00157	.000094	818	1,630	611.8	2.989
H-4		54		155	79	.31	.00157	.00017	810	2,820	338.2	2.427
H-5		78		175	79	.43	.00088	.000126	808	2,140	255.8	2.394
H-6		88		197	79	.58	.00097	.000108	800	1,800	329.0	3.087
H-7		72		176	105	.36	.00075	.000117	797	1,910	234.8	2.334
H-8		76		207	95	.438	.000813	.000096	799	1,660	310.0	3.155
H-9		95		264	100	.5	.000972	.000129	797	2,100	276.0	3.798
H-2A	7.3	50	107	150	63	5.0	.00368	.000062	783	1,110	2,174.0	6.170
H-2A		50	107	150	63	5.0	.00368	.0000634	800	1,080	2,126.0	5.92

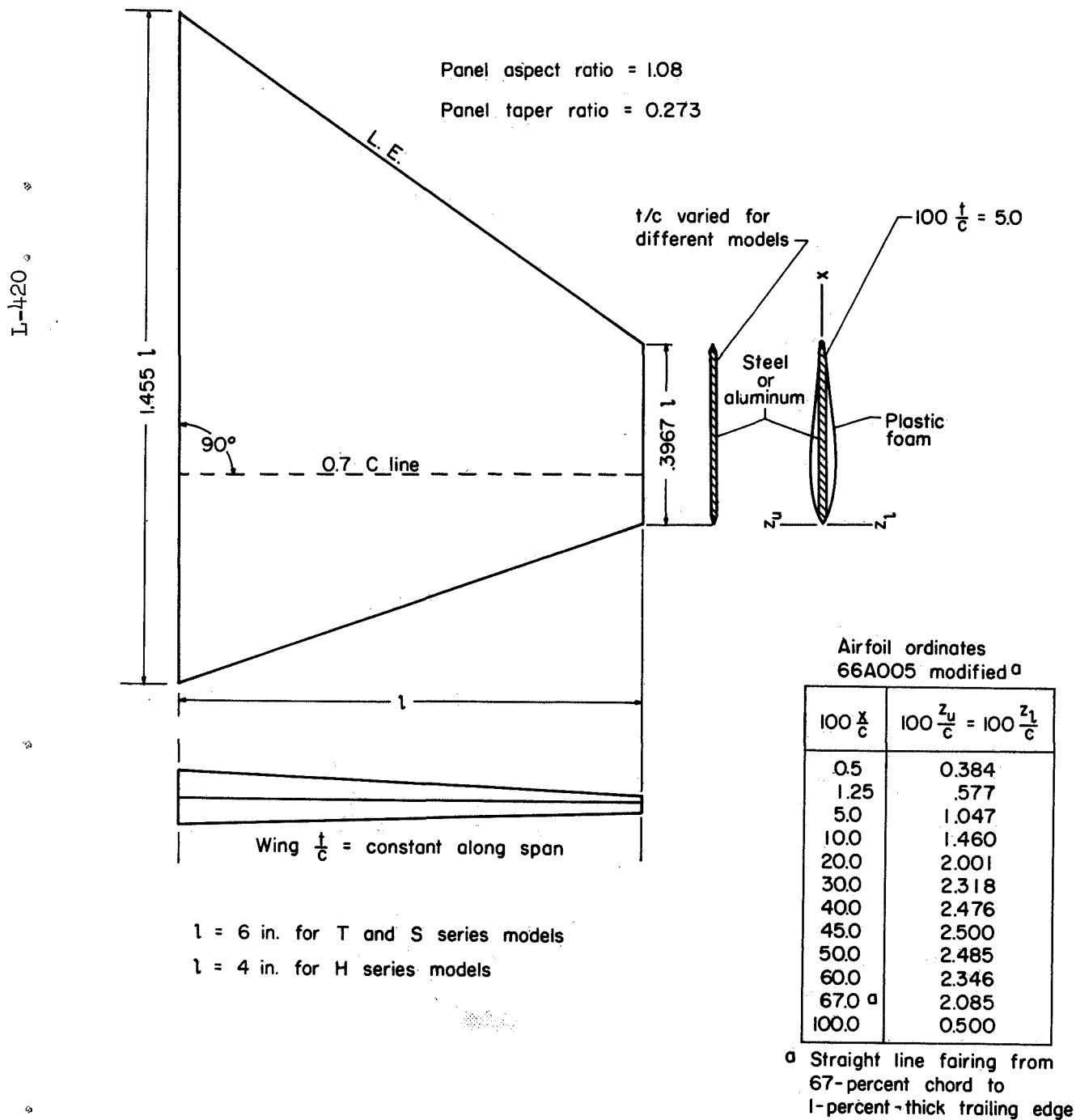


Figure 1.- General dimensions and airfoil sections of models.

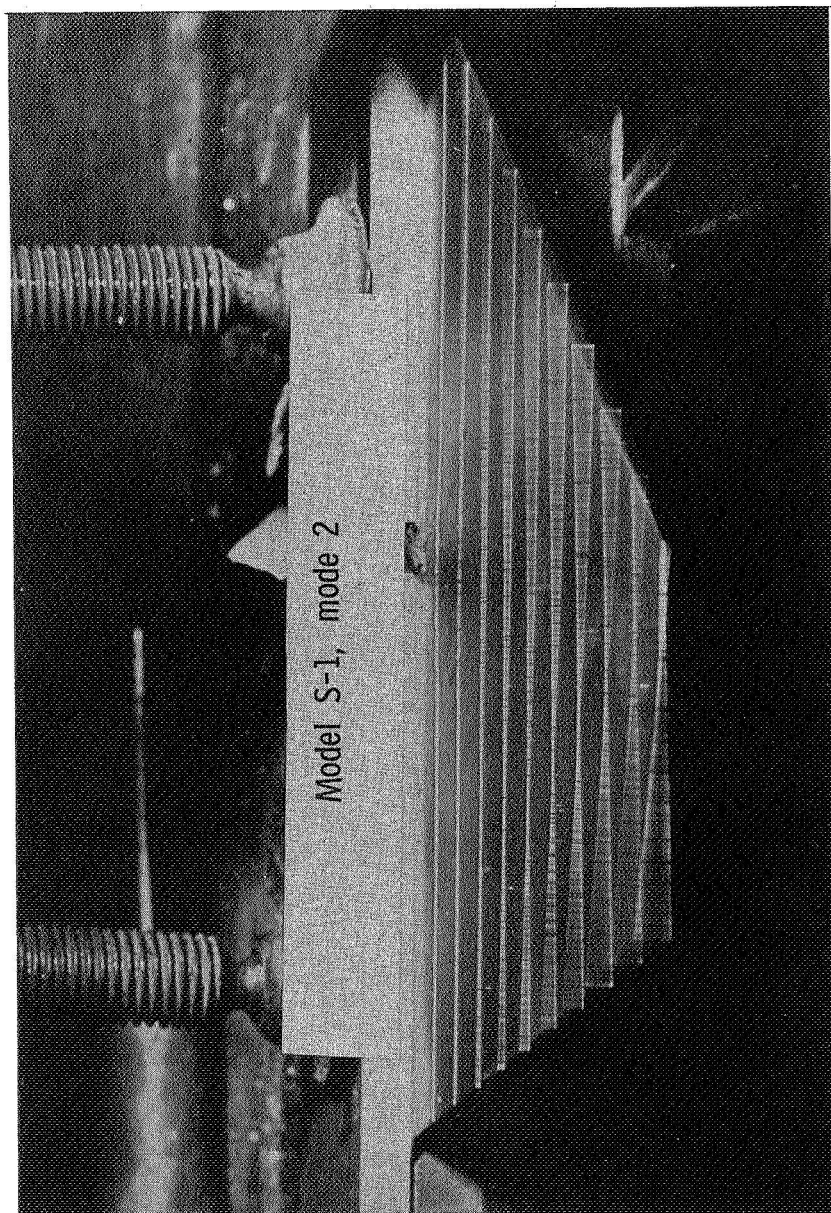
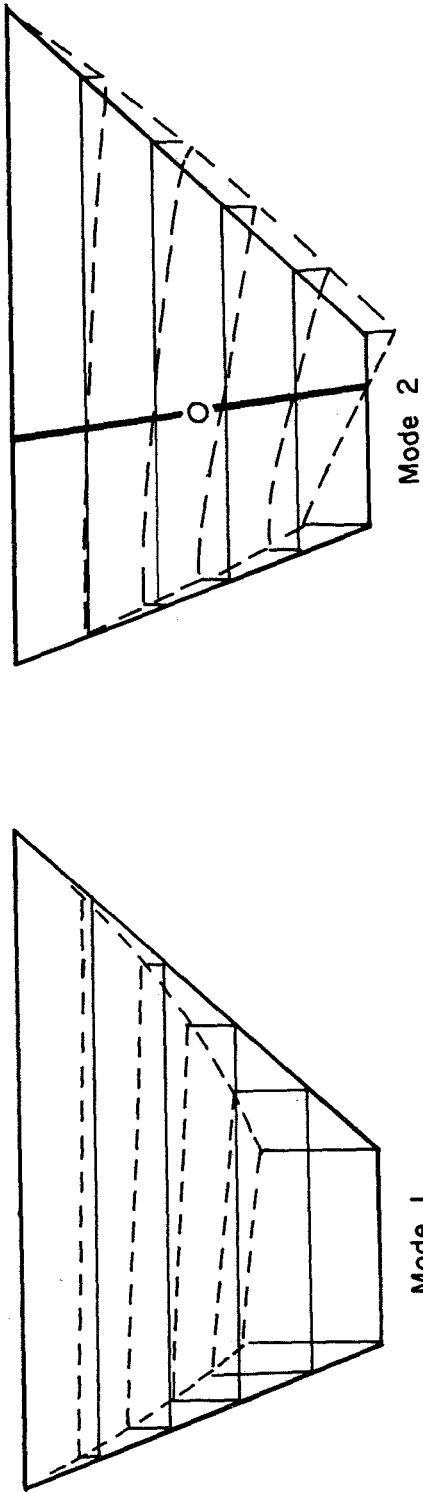


Figure 2.- Laboratory setup for determining natural frequencies and mode shapes of models.
Model S-1 vibrating in the second natural mode.

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—○— Node line
 — Undisturbed position
 --- Disturbed position

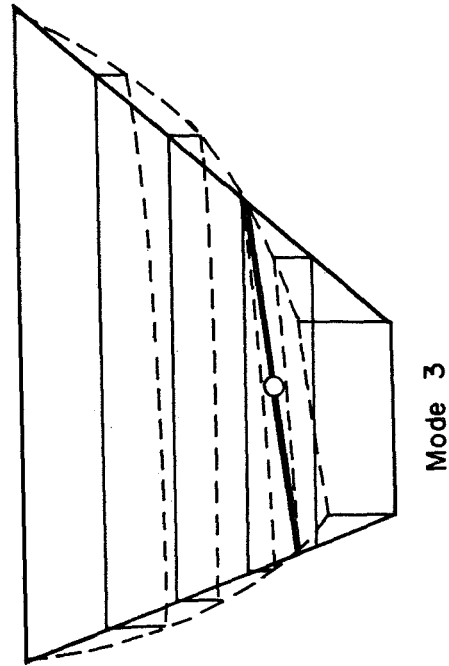
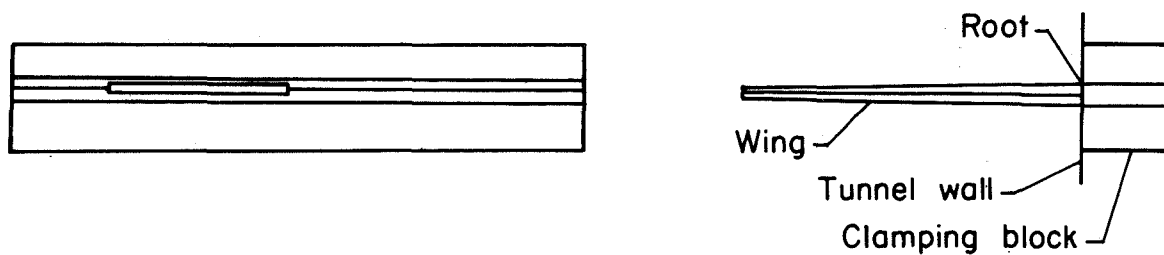
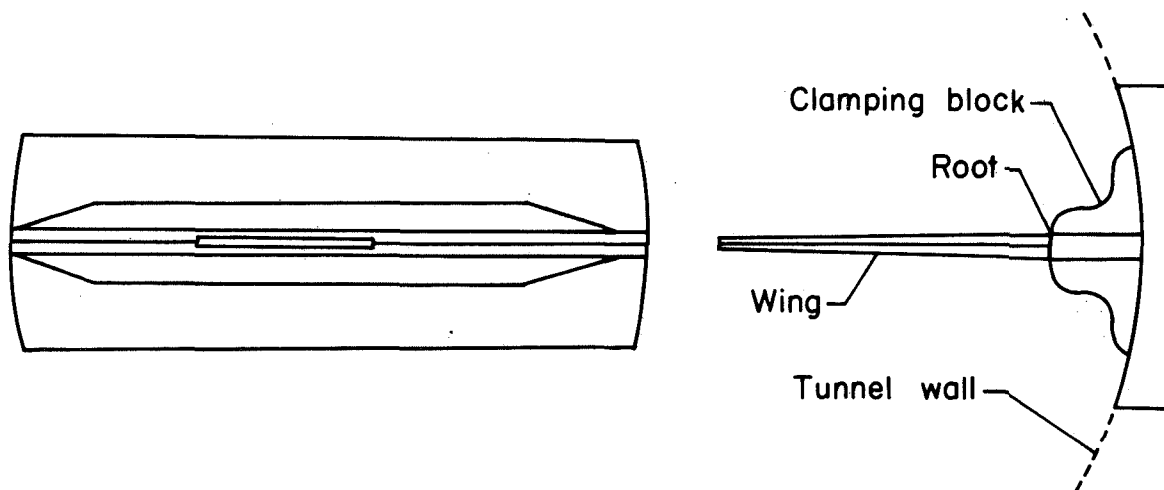


Figure 3.- Sketch of the mode shapes and node lines of model S-1.



(a) Flush mount used for T- and S-series models.



(b) Mount used for H-series model tests.

Figure 4.- Sketch of model mounts used in tests.

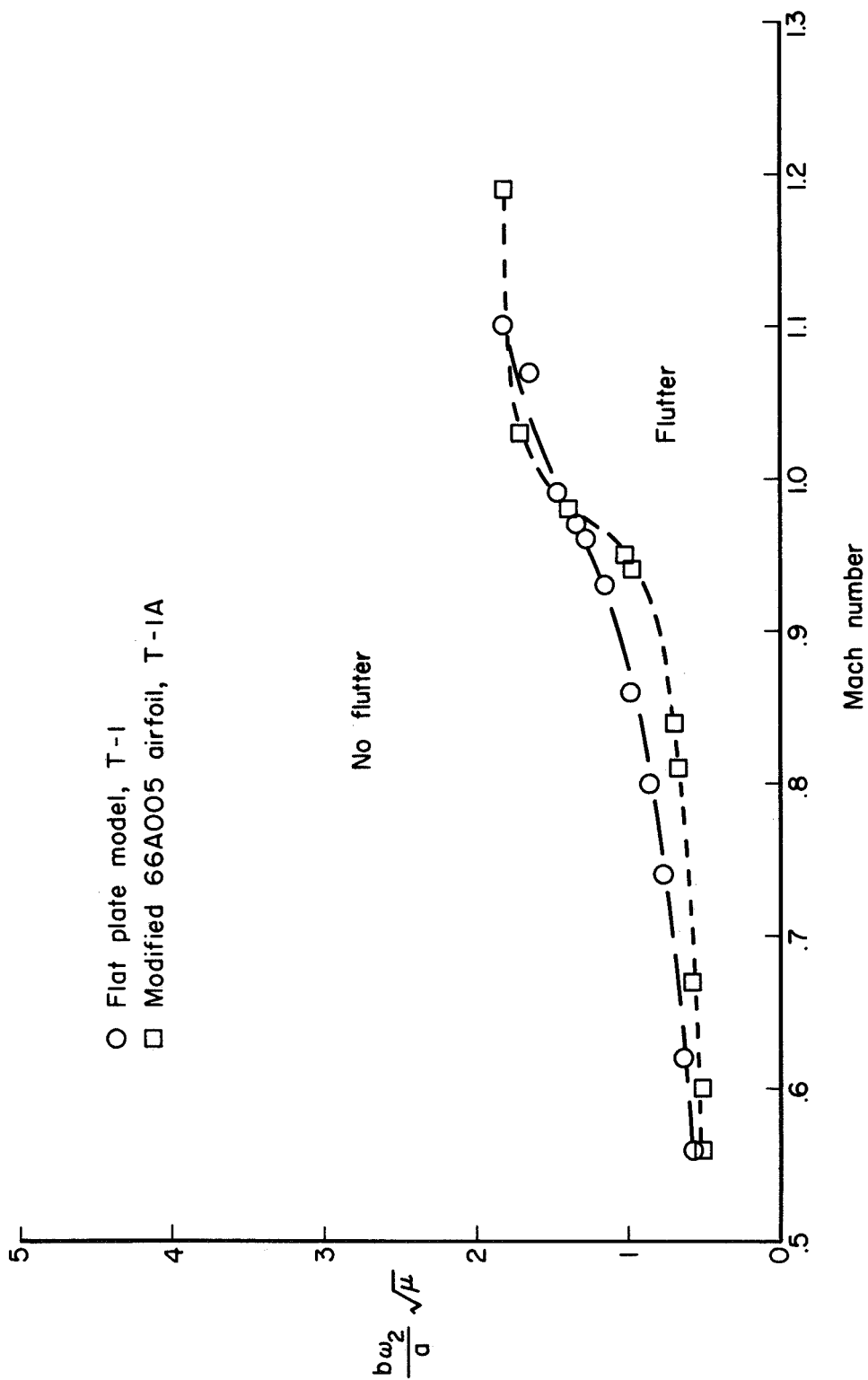


Figure 5.- Comparison of experimental flutter data for flat-plate model and same model with modified 66A005 airfoil section.

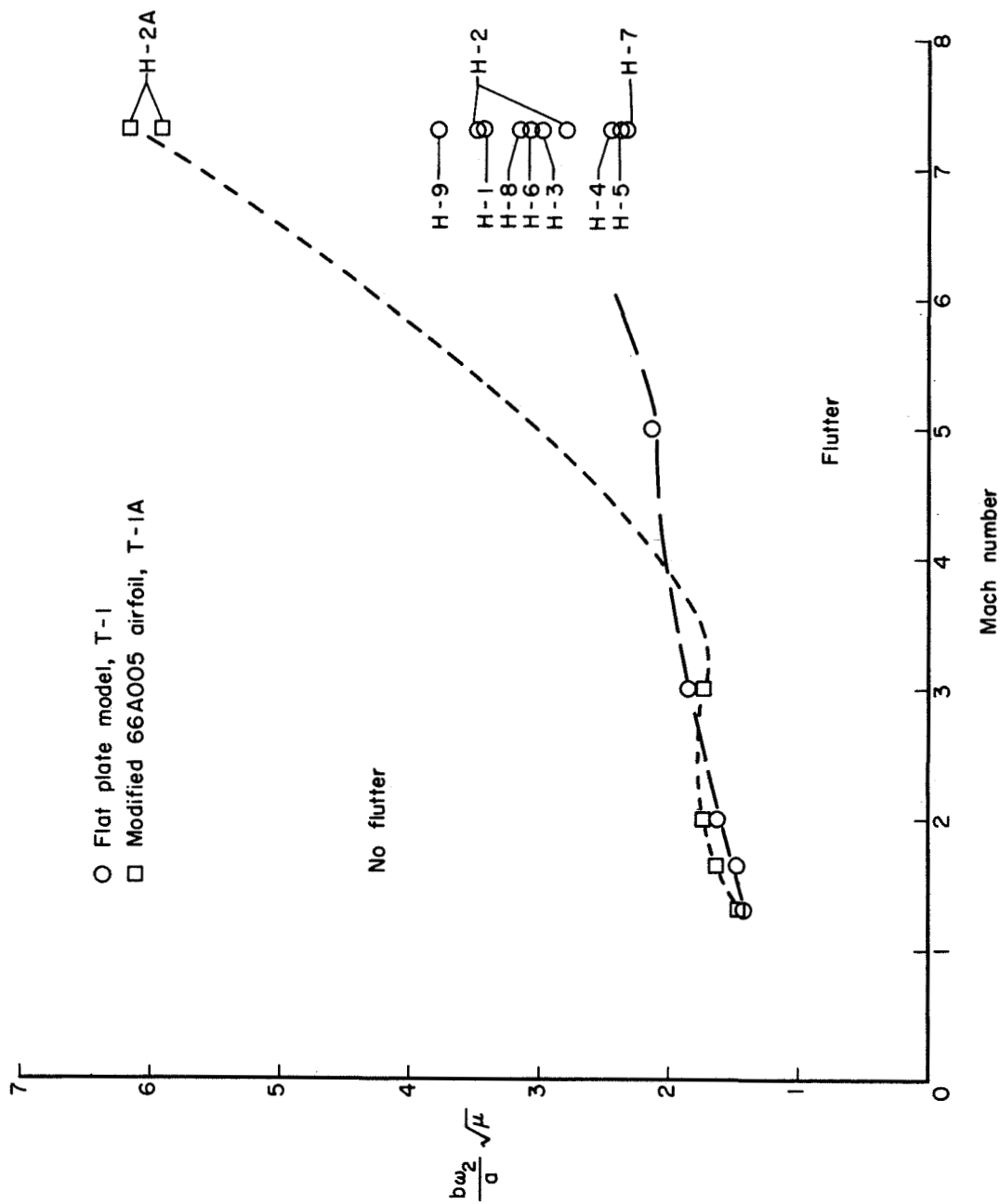


Figure 6.- Comparison of experimental data for flat-plate models and modified 66A005 airfoil models at supersonic and hypersonic speeds.

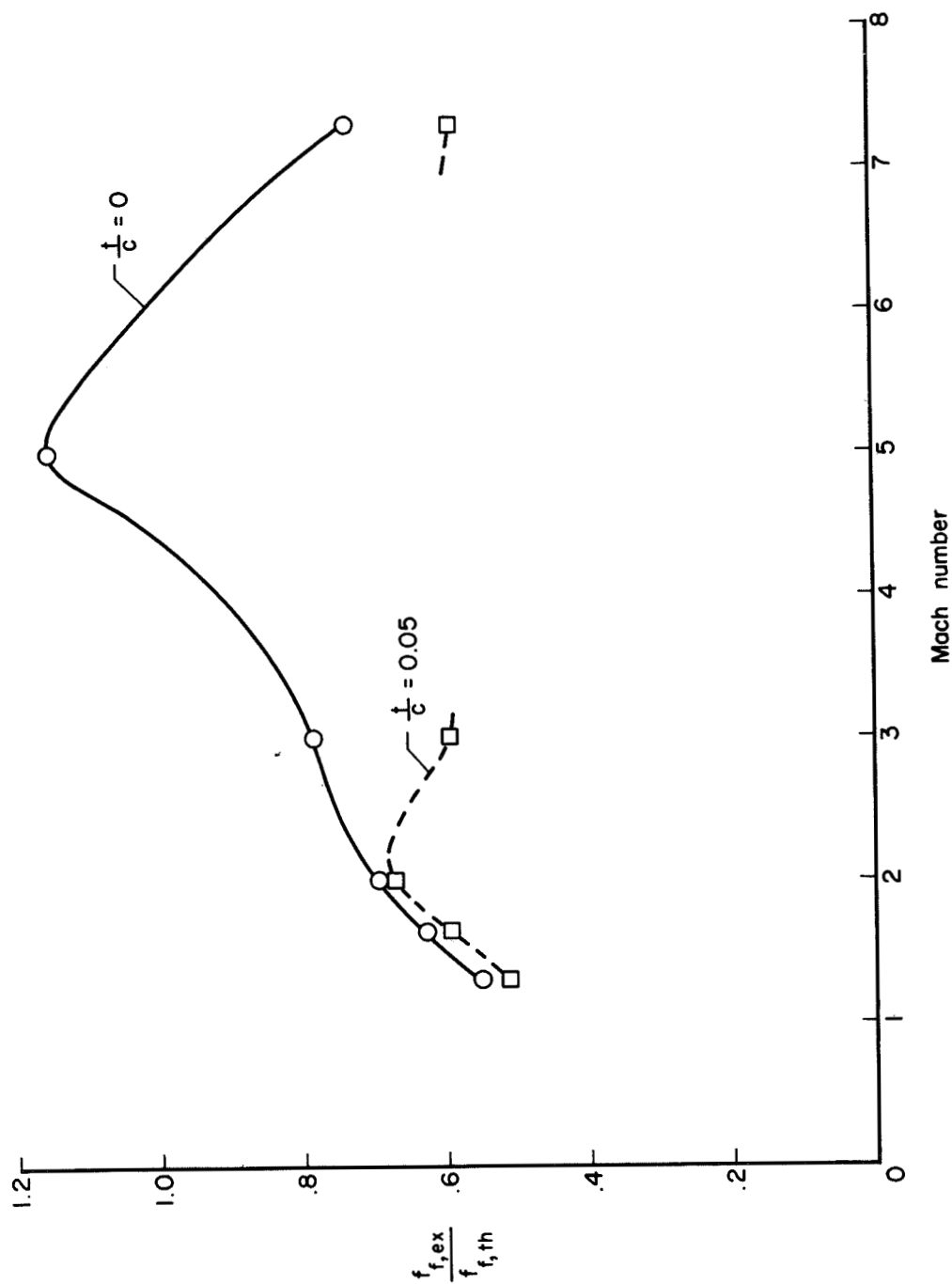


Figure 7.- Comparison of the ratio of experimental flutter frequency to theoretical flutter frequency for the flat-plate model and the modified 66A005 airfoil model in the supersonic and hypersonic Mach number range.

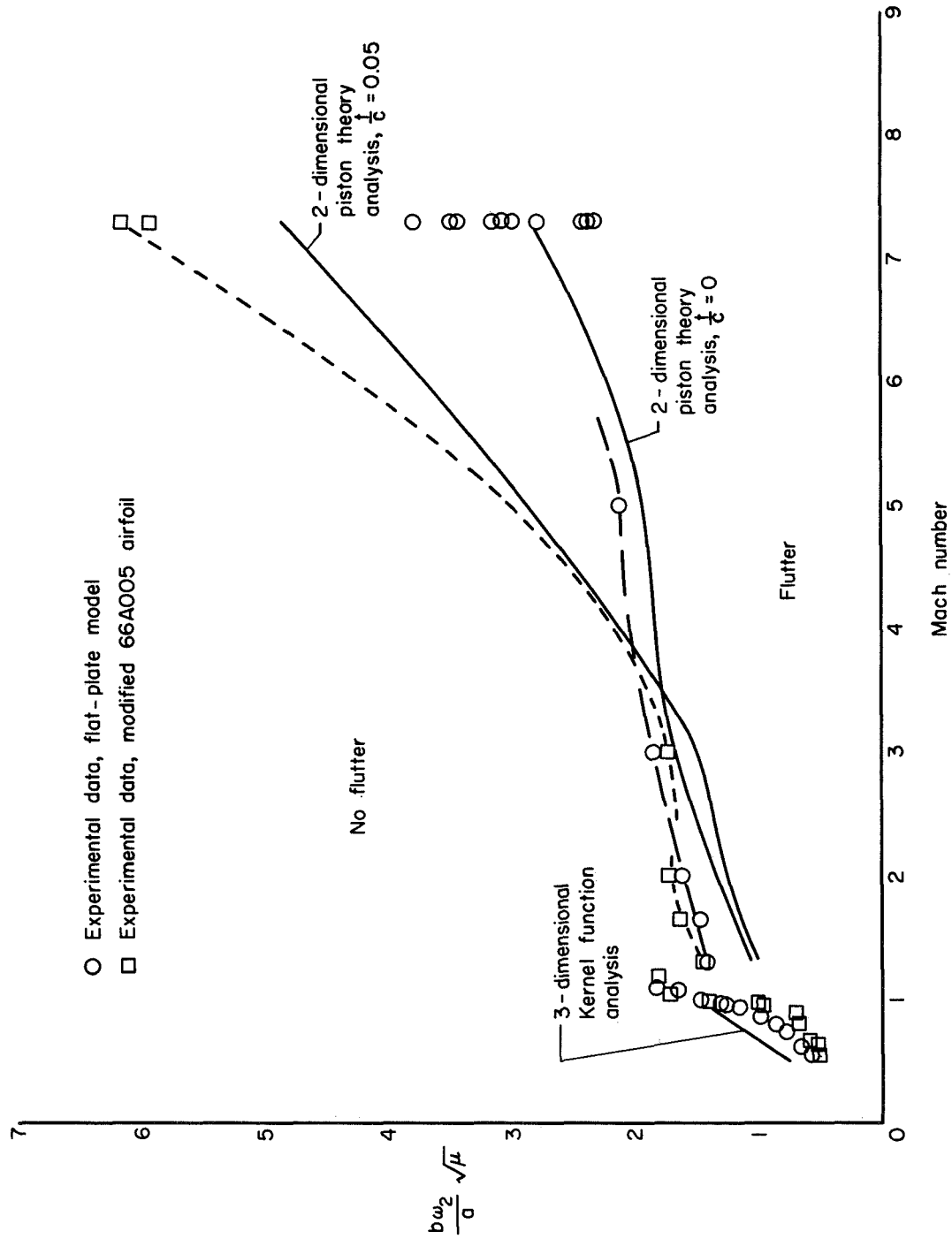


Figure 8.- Summary of experimental and theoretical data.

